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The Effect of Metallicity on the Cepheid Period-Luminosity Relation

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Abstract. We present preliminary results of an observational campaign devoted at establishing the influence of chemical composition on the Cepheid Period-Luminosity relation. The data are in good agreement with theoretical predictions based on non-linear convective models, suggesting a fairly strong dependence of the Period-Luminosity relation on metallicity in the sense of more metal rich stars being intrinsically fainter than otherwise expected. Our data indicate that the error on the inferred distance can be as large as 10% if the role of metallicity is neglected.

1.   Introduction

Ever since the work of Edwin Hubble, the Cepheid Period-Luminosity (PL) relation is a fundamental tool in determining Galactic and extragalactic distances. In spite of its paramount importance, to this day we still lack firm theoretical and empirical assessment on whether or not chemical composition has any significant influence on the pulsational properties of Cepheids.

The debate on metallicity effects on the Period-Luminosity relation is an old one (see, for example, the reviews by Madore & Freedman 1991 and, more recently, Feast 2003), but the matter is far from being settled. As an illustration, different prescriptions on how to account for the metallicity effect lead to differences as large as 10% in the the distance to the Large Magellanic Cloud (e.g. Groenewegen & Oudmaijer 2000), which directly translates into a 10% uncertainty on H_0. To make things worse, this effect is *systematic* and only a careful calibration of the dependence of the PL relation on metallicity can provide firmer ground on which to build the astronomical distance ladder. Regrettably, the current understanding of the subject is poor.

Theoretical pulsational models by different groups lead to markedly different results. On the one side computations based on *linear models* (e.g. Chiosi et al 1992, Sandage et al 1999, Alibert et al 1999, Baraffe & Alibert 2001) suggest a mild dependence of the PL relation on chemical composition (less than 0.1 mag at $\log(P) = 1$ for a change in metallicity between $Z = 0.004$ and $Z = 0.02$). This result is challenged by the outcome of the *non-linear convective models*

(e.g. Bono et al 1999, Caputo et al 2000) which find that both the slope and the zeropoint of the Period-Luminosity relation depend significantly on the adopted chemical composition. Again for $\log(P) = 1$ and the same variation in metallicity as above, they predict a change as large as 0.4 magnitudes in V, 0.3 magnitudes in I and 0.2 magnitudes in K. Moreover, the change is such that metal-rich Cepheids are *fainter* than metal-poor ones, again at variance with the results of Alibert et al (1999) and Baraffe & Alibert (2001). Finally, recent calculations by Fiorentino et al (2002) based on non-linear models indicate that the PL relation also depends on the helium content of the stars.

From an observational standpoint, the subject was approached in essentially two ways: a direct measurement of the iron content in nearby, *i.e.* bright, Cepheids, or by measuring a secondary metallicity indicator in external galaxies known to contain Cepheids, under the assumption that they would have the same chemical composition. Regrettably, *direct metallicity determinations* for individual Cepheids exist only for a handful of stars. The most accurate studies are by Fry & Carney (1997, [Fe/H] and [α/H] for 23 Galactic Cepheids) and Andrievsky et al (2002, complete abundance analysis of 77 Galactic Cepheids; see also Luck et al 2003). The former find a spread in [Fe/H] of 0.4 dex, which they argue is real, the latter focus on investigating Galactic abundance gradients (-0.05 dex/kpc). Luck et al (1998) have measured the iron abundance of 16 Cepheids in the Large and Small Magellanic Cloud (LMC and SMC, respectively) with the echelle spectrograph at the CTIO 4 meter telescope. The relatively small size of the telescope forced them to choose only stars at the bright end of the Period-Luminosity relation, *i.e.* long periods, whereas the entire range needs to be sample in order to reach meaningful conclusions on the PL relation (e.g. Kennicut et al 1998, Caputo et al 2000). As for the *indirect measurements* in external galaxies (e.g. Kochanek et al 1997, Kennicutt et al 1998), which probe a broader range in metallicity than the one available in the Galaxy, they find that metal-rich Cepheids are *brighter* in V and I than metal-poor ones by 0.24 to 0.40 magnitudes per dex in metallicity. These results have been widely used in the literature, including in the final paper of the HST Key Project on H_0 (Freedman et al 2001).

2.   The Data Sample

With the scenario described above in mind, we have collected high quality spectra of an unprecedented dataset of 40 Galactic, 22 LMC and 14 SMC Cepheids with the aim of measuring metallicity directly on a statistically significant sample of stars covering about one order of magnitude in chemical composition. The Galactic stars were observed with FEROS at the ESO 1.5m telescope on La Silla at a spectral resolution of 48,000 with a signal-to-noise ratio of about 70 to 150. As for the spectra of the Magellanic Cloud objects, we used the UVES spectrograph on the Kueyen telescope on Cerro Paranal, yielding a resolution of 40,000 and signal-to-noise ratio of about 50 to 70.

Deriving metallicities for Cepheids is by no means a trivial task, but we have now carefully analyzed and derived [Fe/H] for an initial subsample of 14 Cepheids in the LMC, 12 in the SMC and 6 in the Galaxy. The data reduction procedures and analysis are described in detail in Mottini et al (2003).

3.   Results: dependence of the PL relation on metallicity

The main result from the subset analyzed so far is summarized in Figure 1. There, we plot the V-band residuals from the standard Madore & Freedman (1991) *PL* relation as a function of the iron abundance derived from FEROS and UVES spectra. A positive magnitude difference here means that the star is fainter than the mean *PL* relation. For consistency with the adopted *PL* relation, the LMC is assumed to have a distance modulus of 18.50. The SMC is considered 0.44 mag more distant (e.g. Cioni et al 2000) and the distances to Galactic stars were taken from Fouqué et al (2003), Barnes et al (2003) and Tammann et al (2003). Photometry and reddening are taken from Laney & Stobie (1994).
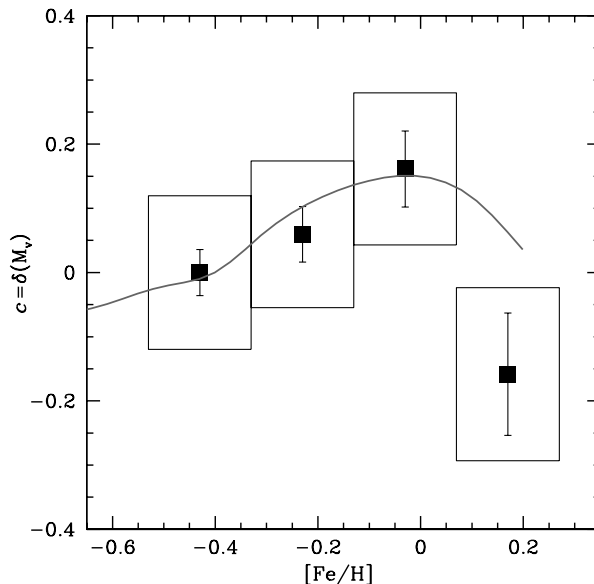

Figure 1.   *V*-band residuals compared to the Madore & Freedman (1991) *PL* relation vs the iron content we have measured from our UVES and FEROS spectra (14 stars in the LMC, 12 in the SMC and 6 in the Galaxy). Filled squares represent the median value in each metallicity bin with its associated errorbar and the rms in each bin is displayed as boxes. The solid line shows the predictions by Fiorentino et al (2002).

The data are binned in metallicity to reflect the typical observational error on our determination (± 0.1 dex). The Magellanic Cloud Cepheids populate the bins at lower metallicity, the higher [Fe/H] one containing only Galactic stars. The median magnitude residual in each bin is plotted as a square and the rms and error on the median are shown as boxes and errorbars, respectively. The magnitude difference plotted on the ordinates can be directly compared to the "*c*" quantity computed by Fiorentino et al (2002). This is the correction to be applied to the distance modulus derived using a universal, metallicity independent *PL* relation to take into account the influence of metallicity as derived from their non-linear pulsation models.

The agreement between our data and the predictions by Fiorentino et al (2002), indicating a strong dependence of the PL relation on metallicity, is tantalizing, even though the errorbars are still somewhat large. As it can be seen, the error on the inferred distance can be as large as 10% if the effect of metallicity is neglected.

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